**Magnetohydrodynamic Energy Conversion R&D**

Woodside¹, Richards¹, Ochs¹, Huckaby¹, Oryshchyn¹, Kolczynski¹, Felman¹², Kim¹, Weiland¹, Bedick¹⁴, Haworth³, Dasgupta³, Cann², Singh³, Nielsen¹, McGregor¹², Gibson², Bokii², Celik², Escobar², Lineberry³

Generating a knowledge base, data sets, and tools toward predicting and improving MHD power generation technology performance

**CFD simulation of MHD generator**

1D Steady State Model

\[
\frac{d (\rho u)}{dt} + \nabla \cdot (\rho u u) = -\nabla \cdot \mathbf{J} + \frac{d P}{dt}
\]

\[
\frac{d (\rho E)}{dt} + \nabla \cdot (\rho E u) = \frac{d}{dt} \left( \rho u \right) + \nabla \cdot \mathbf{J} \times \mathbf{B}
\]

\[
\rho = \frac{P}{u} + \frac{1}{2} \rho u^2 + \frac{1}{2} \rho E
\]

Simulations of a preliminary design for the NETL MHD generator experiment

- Sensitivity to channel profile

Multidimensional CFD

- Adjusted complexity of physical models
- Based on OpenFOAM CFD Toolbox
- Dynamic Fluids:
  - Equilibrium and non-equilibrium models for composition (ionization), momentum and energy
- Maxwell’s equations:
  - Electric potential and full Maxwell’s equation approaches
- Transport & Collision
  - Cross-section and transport properties from open databases, additional calibration to NETL experiments

Simulations with different fidelity developed for:

- Experimental design
- System performance
- Detailed generator optimization

New submodels are being developed for:

- Wall functions*, ionization
*Classical log-law does not apply with magnetic field

Simulation of Hartmann flow cases (i.e. with Lorentz force).

Comparison of DNS to CFD with wall functions.

**MHD bench scale experiment (planned) — A staged approach to provide experience and model validation.**

Test System Design Phase Work:

1. Component testing
   - Systems shake down
   - Establish HVOF combustion system heat losses/fluxes
   - Channel material exposure to temperature and flow

2. Back-powered “Hall Channel” experiment
   - Establish plasma ionization & conductivity in channel
   - Demonstrate current density spatial profiling (see below)
   - Channel material exposure to temperature, flow, and electricity

3. Combined, bench-scale MHD experiment
   - Validate and improve MHD simulations
   - Channel material exposure to full open-cycle MHD conditions

**Electric Current Density Detection for MHD**

The goal is to model, detect and eventually control arcs in a MHD generator. Inverse problem: current flux via external measures of induced magnetic field.

```
\sigma = \sigma (E, T, p, Y)
\sigma = \sigma (E, T, p, Y)
```

```
E = E + \sigma (E, T, p, Y)
E = E + \sigma (E, T, p, Y)
```

```
\sigma = \sigma (E, T, p, Y)
\sigma = \sigma (E, T, p, Y)
```

```
\frac{d}{dx} E + \sigma (E, T, p, Y) = 0
\frac{d}{dx} E + \sigma (E, T, p, Y) = 0
```

Comparison of potential MHD power density for various cases as a function of Mach #. Karoosite was selected.

A designed “Hall Channel” showing calculated material temperatures (above) and thermal stresses (below).

**Measurement of electrical conductivity in seeded oxy-fuel flames**

Conductivity measurements used to validate predictions:
- Literature cross sections lead to >2x uncertainty in conductivity.
- Oxy-fuel operation has high CO2 concentration versus earlier studies.
- Double Langmuir probe (transient) in 25mm oxy-fuel flame.
- Planar laser induced fluorescence used to characterize flame profile

**Ceramic Electrode Processing and Characterization**

Baseline “Hot” Electrodes:

1) La₉₅Mg₅CrO₃
2) 88% ZrO₂ – 12% Y₂O₃
3) 89% ZrO₂ – 10% Sc₂O₃ – 1% Y₂O₃
4) 82% HfO₂ – 10% CeO₂ – 8% Y₂O₃
5) 85% HfO₂ – 17% In₂O₃

-Ceramic specimens were fabricated through Field Assisted Sintering (FAST) and conventional pressureless sintering
- Crystal structure via x-ray diffraction
- Electrical conductivity characterized via high temp. impedance spectroscopy

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-Discretize with MFD to solve problem
-Simplified PDE equation system (above)
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**Contact email:** Rigel.Woodside@netl.doe.gov